Early Season Northwest Flow Snowfall Event
28 October 2008

Scott Krentz
NOAA/National Weather Service
Greer, SC

1. Introduction

A post frontal northwest flow snowfall event affected the mountains of North Carolina on 28 October 2008 between 0200 UTC and 1800 UTC. Snowfall totals ranged from a trace in the mountain valleys to around 3 inches in the favored upslope regions (Fig. 1). An isolated snowfall report of 6 to 8 inches was received from the Cowee Mountains in western Jackson County, NC. The event occurred earlier in the fall than most measurable snowfall events in western North Carolina. It was the first snow requiring the issuance of Winter Weather Advisories in the 2008-09 winter season.

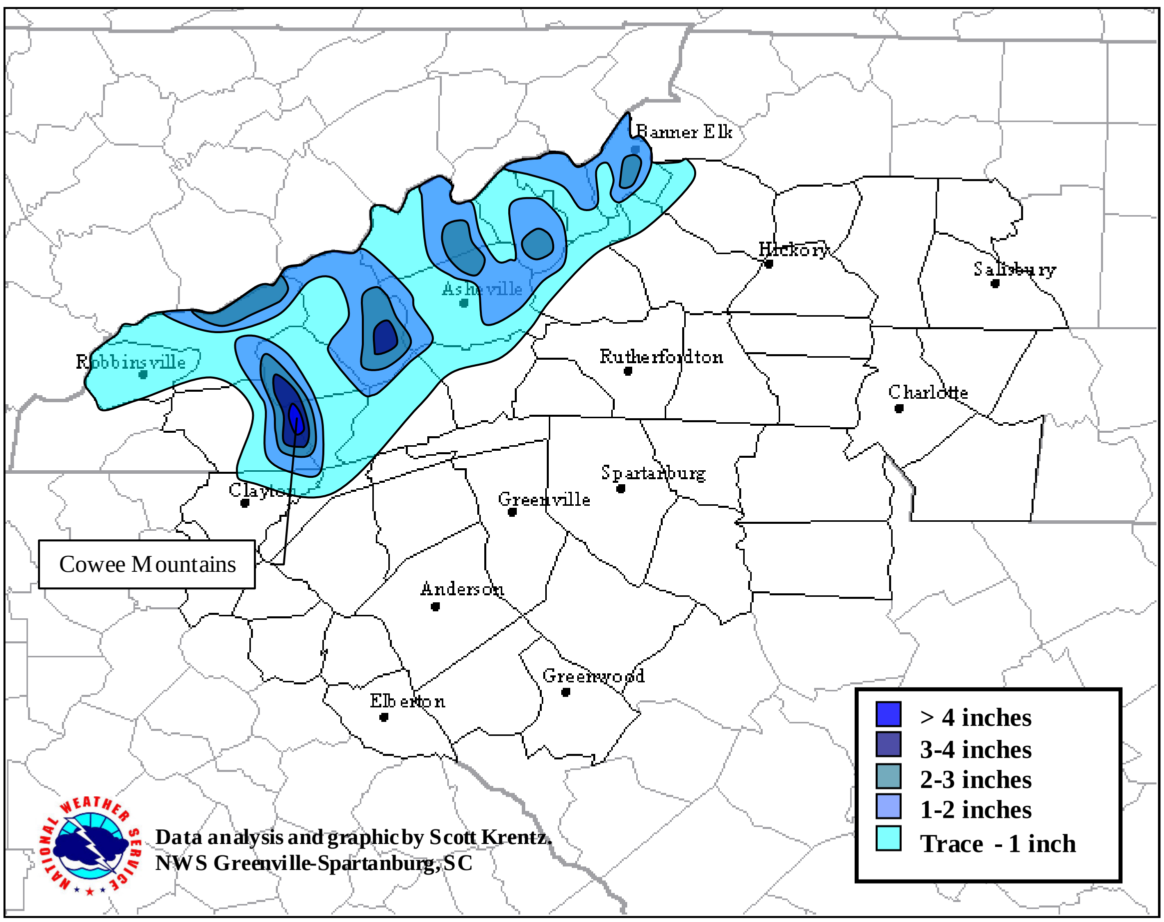

Figure 1. Storm total snowfall 28 Oct 2008.

2. Synoptic Overview

A deep upper level trough dominated the weather pattern across the eastern United States on 28 October 2008. The 0000 UTC radiosonde observation (RAOB) network showed a 150 kt jet core at 250 mb (Fig. 2) along the base of the upper level trough indicating eastward progression of the system during the next 24 hours. At 500 mb, temperatures dropped throughout the day across the western Carolinas from -13°C at 1200 UTC to -30°C by 0000 UTC on 29 October 2008.

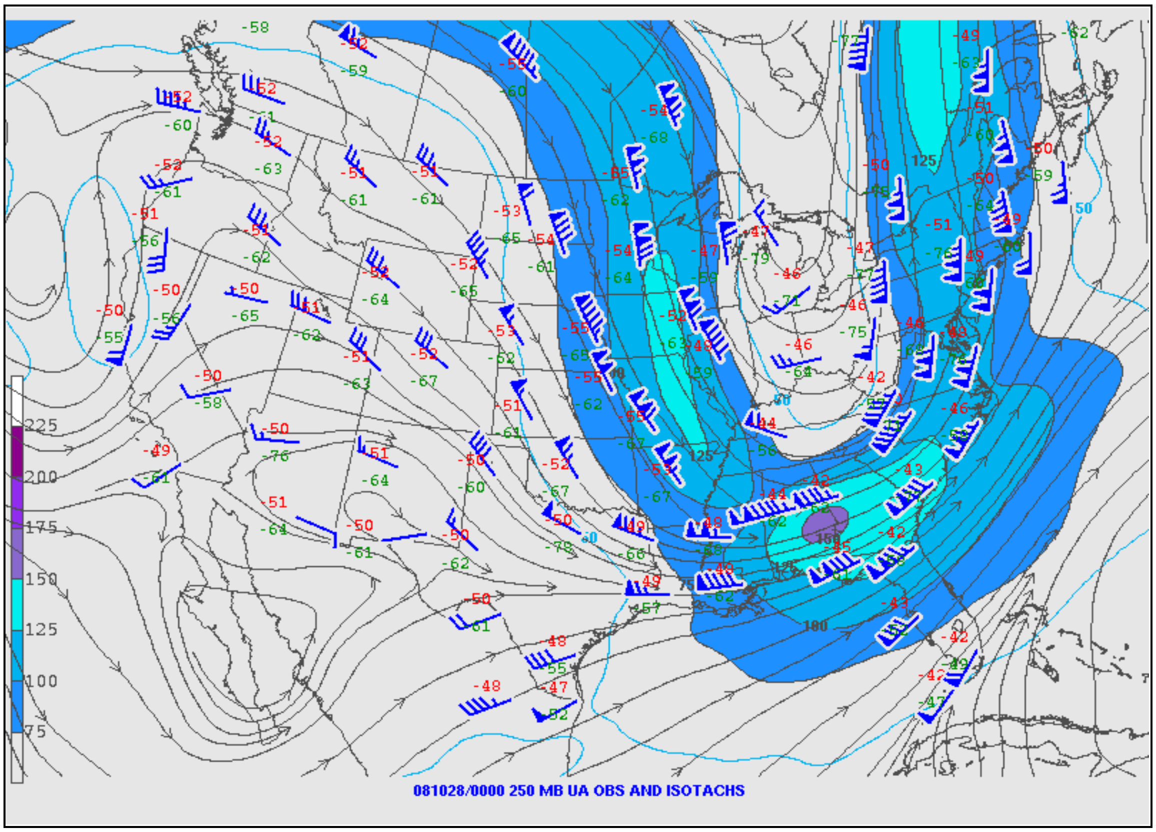

Figure 2. Fig. 2. 250 mb analysis at 0000 UTC 28 Oct 2008. Lines with arrows are streamlines. Shaded isotachs highlight a 150 kt jet maximum.

A cold thermal trough at 850 mb moved slowly over the Tennessee Valley with temperatures across the western North Carolina mountains dropping from -2°C at 1200 UTC on 27 October to -7°C by 1200 UTC the following day (Fig. 3). The atmosphere was dry across the Tennessee Valley at 1200 UTC. The Nashville International Airport (KBNA) RAOB at 1200 UTC 27 October (not shown) indicated an 850 mb dew point depression of 9°C. By 0000 UTC 28 October, moisture advection from the Midwest and afternoon mixing due to boundary layer heating decreased 850 mb dew point depressions to 3°C. Visible satellite imagery captured the increase in moisture (Fig. 4) during the day as an expansion of the cumulus and stratocumulus cloud field across middle and east Tennessee.

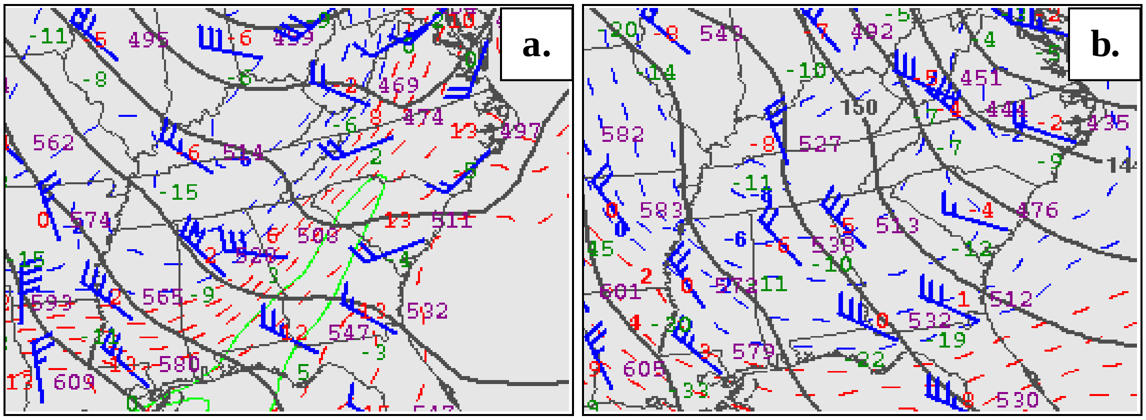

Fig. 3. 850 mb height contours (solid lines), isotherms (dashed lines) and station plots for (a) 27 Oct 2008 1200 and (b) 28 Oct 2008 1200 UTC. Note the decrease in temperature across western North Carolina from -2°C to -7°C.

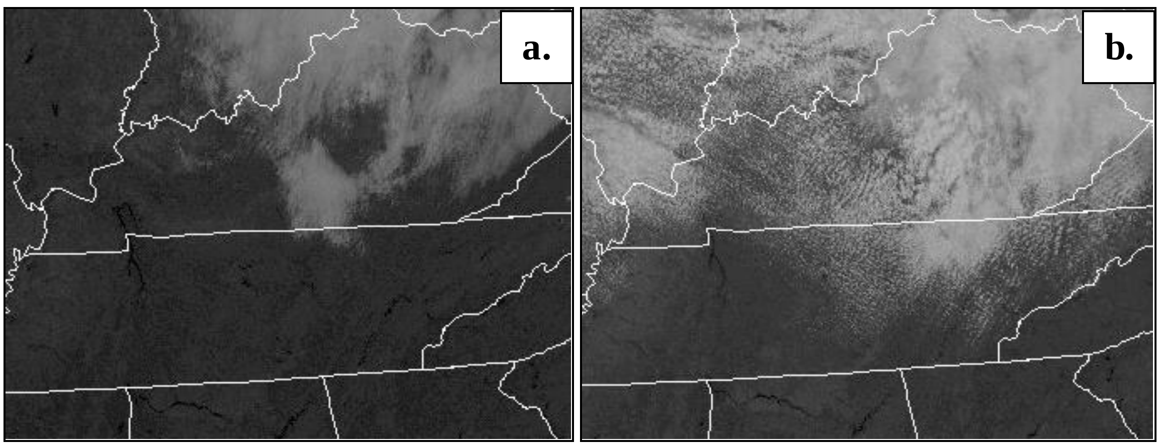

Fig. 4. 27 Oct 2008 1445 UTC GOES visible imagery at (a) 1445 UTC and (b) 1745 UTC. Note the expanding cumulus and stratocumulus cloud field across middle and east Tennessee. Wave clouds have developed east of the Cumberland Plateau.

At the surface, a strong 1040 mb high pressure system was centered over the Great Plains at 1200 UTC 27 October 2008 (Fig. 5) with a ridge extending across the Tennessee and Ohio valleys. A cold front was located along the East Coast, and it was rapidly moving toward the Atlantic Ocean ahead of the progressive upper trough. Surface observations at 1200 UTC indicated temperatures across the Tennessee Valley were in the middle 40s F. Dew points in the ridge axis were in the lower to middle teens while dew points to the northwest and southwest of the ridge axis were generally in the middle 20s °F and middle 30s °F, respectively.

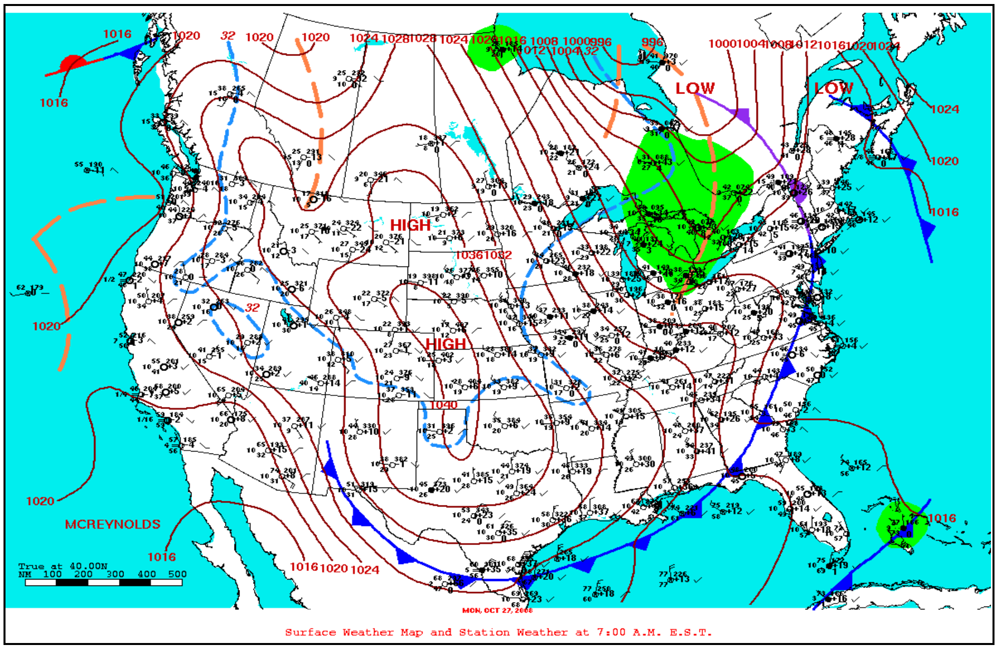

Fig. 5. Surface analysis at 1200 UTC 27 Oct 2008.

The 1200 UTC 28 October 2008 surface analysis (Fig. 6) coincided with the final hours of the event. A low pressure system was centered over the northeastern states, a high pressure system was over the Midwest, and a tight pressure gradient between the two produced northwest wind and upslope flow across the central and southern Appalachians.

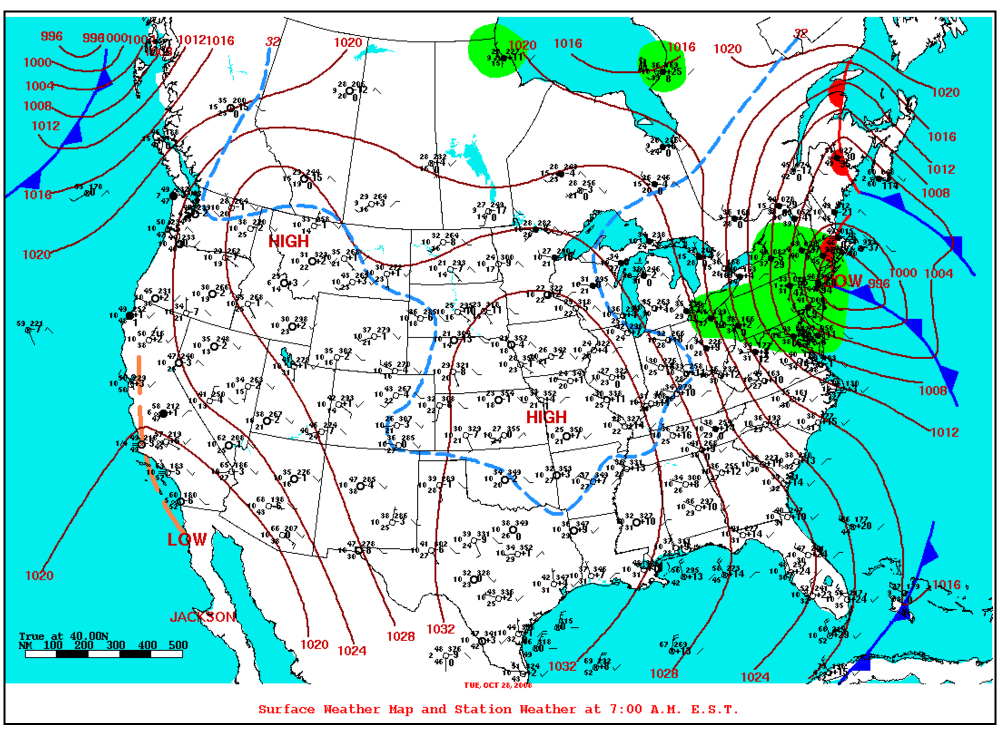

Fig 6. Surface analysis at 1200 UTC 28 Oct 2008.

The 1200 UTC 27 October BUFKIT WRF NAM sounding at Tri Cities Regional Airport (TRI) in eastern Tennessee revealed a dry air mass with precipitable water of 0.32 inches. By 0000 UTC, the TRI model sounding (Fig. 7) had become unstable in the low levels with a dry adiabatic lapse rate extending up to 800 mb. Northwest winds from the surface to 400 mb existed on the 0000 UTC 28 October model sounding. The mean 0-6 km wind was 22 kt from 315^{o}. The air mass west of the Appalachians contained a small amount of positive energy as indicated by the surface based CAPE of 31 J kg^{-1} on the 0000 UTC 28 BNA RAOB (not shown).

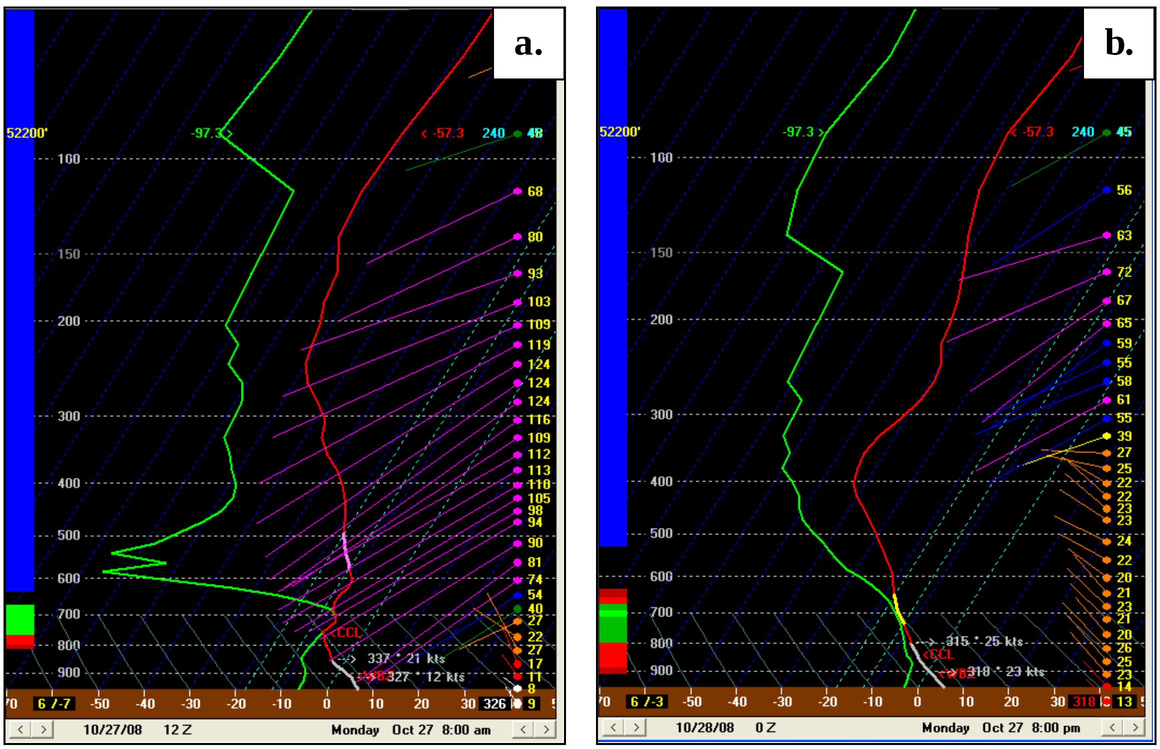

Fig. 7. BUFKIT WRF NAM model sounding for TRI at 1200 UTC 27 Oct 2008 (a) indicating low precipitable water values. The TRI model sounding at 0000 UTC 28 Oct 2008 (b) showing a saturated region between -10°C and -20°C (yellow line) and strengthening northwest flow.

Satellite imagery showed low level cloud cover increasing throughout the afternoon across the upper Tennessee Valley. Cellular convective clouds, topographically induced wave clouds, and cloud streaks suggestive of the horizontal convective rolls described by Schultz et al. (2004) existed across Kentucky and Tennessee on the 2045 UTC 27 October GOES visible image (Fig. 8). With decreasing 850 mb temperatures, northwest flow, and a saturated low level air mass upstream of the southern Appalachians, the atmosphere was being primed for a northwest flow snow event across western North Carolina.

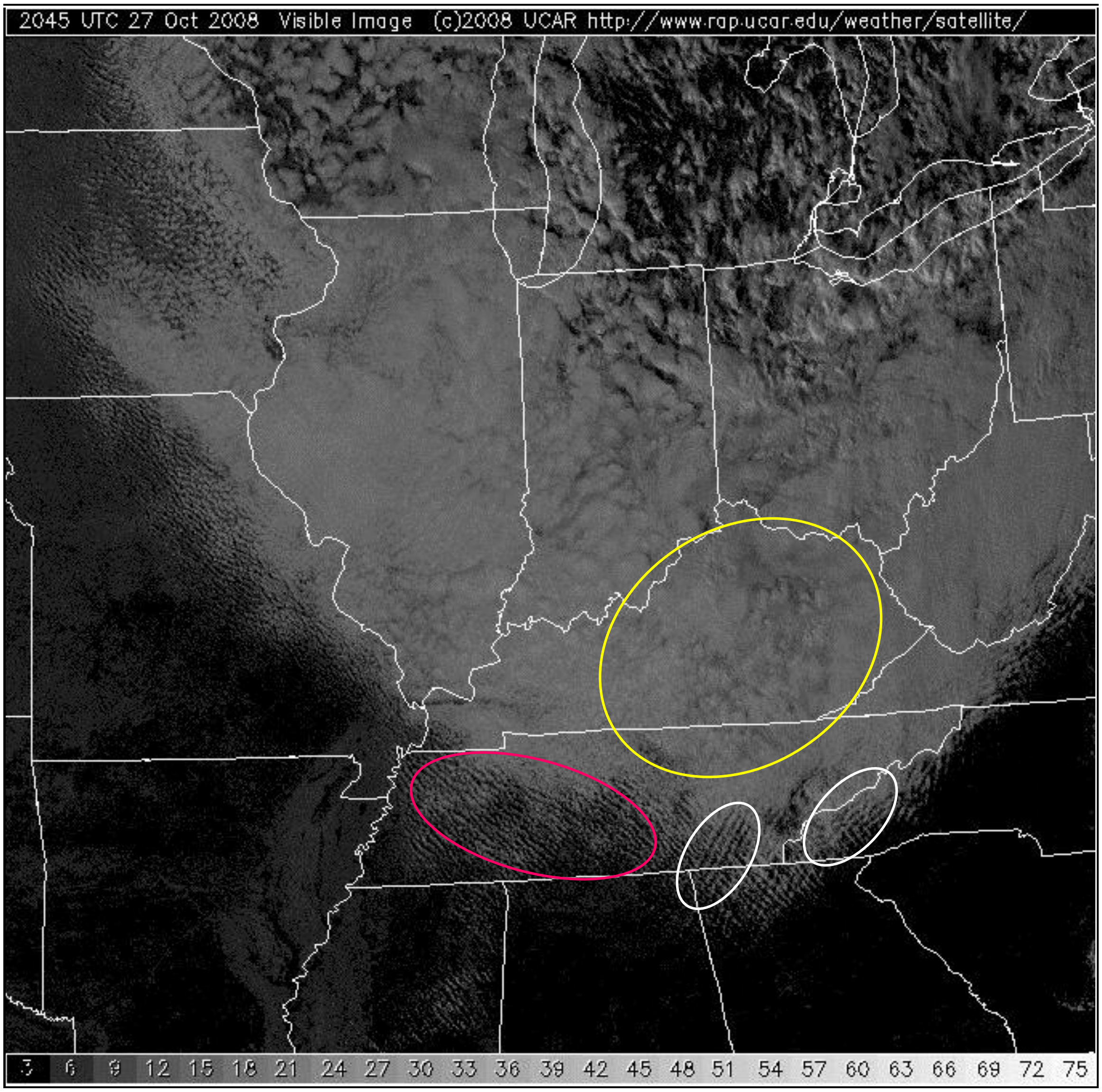

Fig. 8. GOES visible image at 2045 UTC 27 Oct 2008 showing cellular development (yellow oval), topographically-forced wave clouds, and horizontal convective rolls (red oval). Cross-hatched cloud pattern (white ovals) is caused by coexistence of horizontal convective rolls and wave clouds.

3. Northwest Flow Snow Event

Regional composite radar imagery at 0300 UTC (Fig. 9) indicated reflectivity returns across southeastern Tennessee south of Interstate 40 with additional returns across northeastern Buncombe County, NC. The reflectivity returns over northern Buncombe County coincided with a climatologically favored windward slope region for North Carolina northwest flow events (Fig. 10; Perry et al. 2007). Snowfall began in middle Tennessee at Crossville, TN Memorial Airport (CSV) at 0400 UTC 28 October and at the Franklin, NC County Airport (1A5) by 0431 UTC.

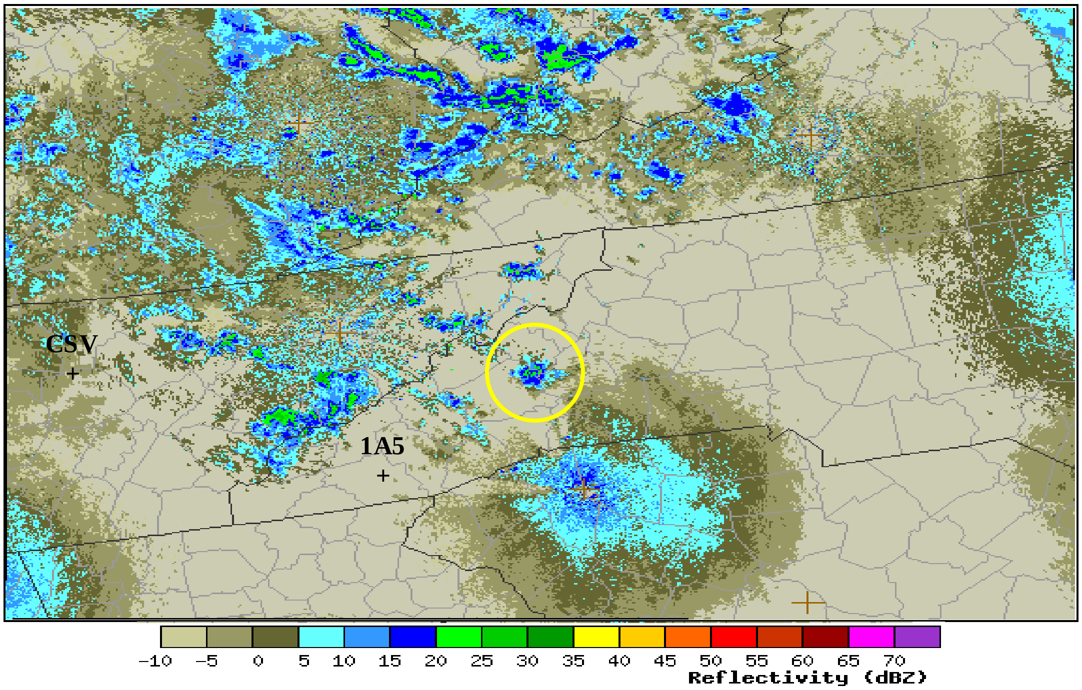

Fig. 9. Composite radar reflectivity at 0300 UTC at the beginning of northwest flow event across western North Carolina. Yellow circle indicates reflectivity in the vicinity of a climatologically favored windward upslope area.

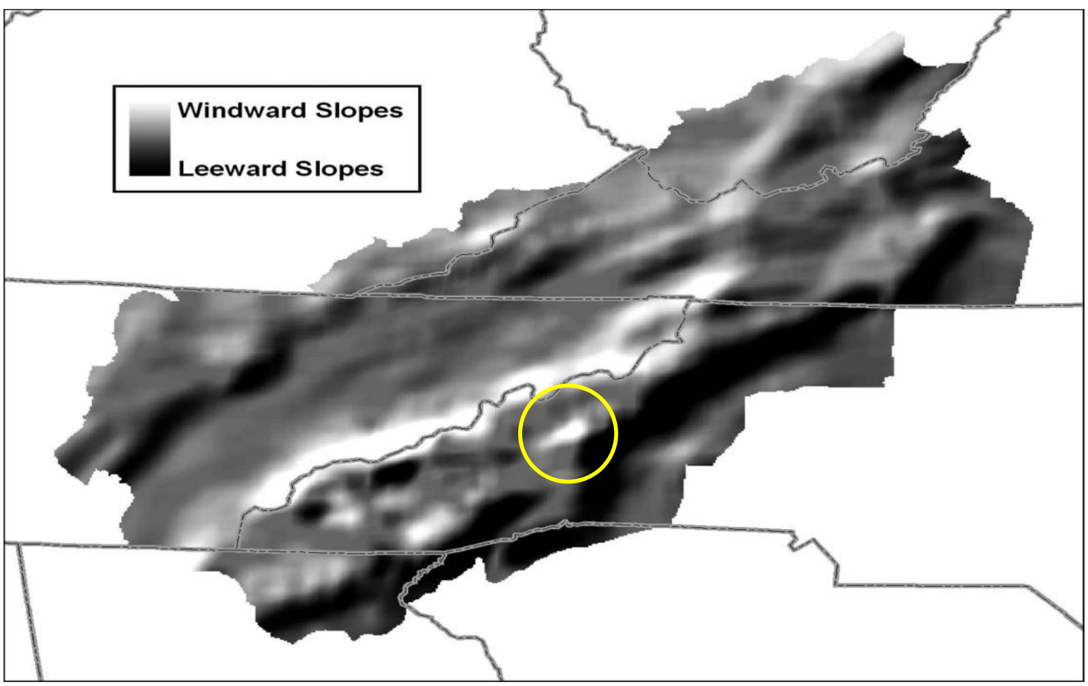

Fig. 10. Windward (light shades) and leeward (dark shades) slopes in northwest flow regimes (Perry et al. 2007). The area in northeast Buncombe County (yellow circle) coincides with composite radar reflectivity maximum seen in Fig. 9.

By 0557 UTC, northwest flow snow bands were developing across the southern and central North Carolina Mountains with increasing echo returns (Fig.11) over Madison County, NC and the Balsam Mountains. Infrared satellite imagery indicated upstream moisture in the form of an extensive low level cloud field (Fig. 12) at 0545 UTC. Cloud top temperatures were generally between -15°C to -20°C, indicative of a saturated layer in the favored dendritic snow crystal growth region (Cotton and Anthes 1989, 106-109).

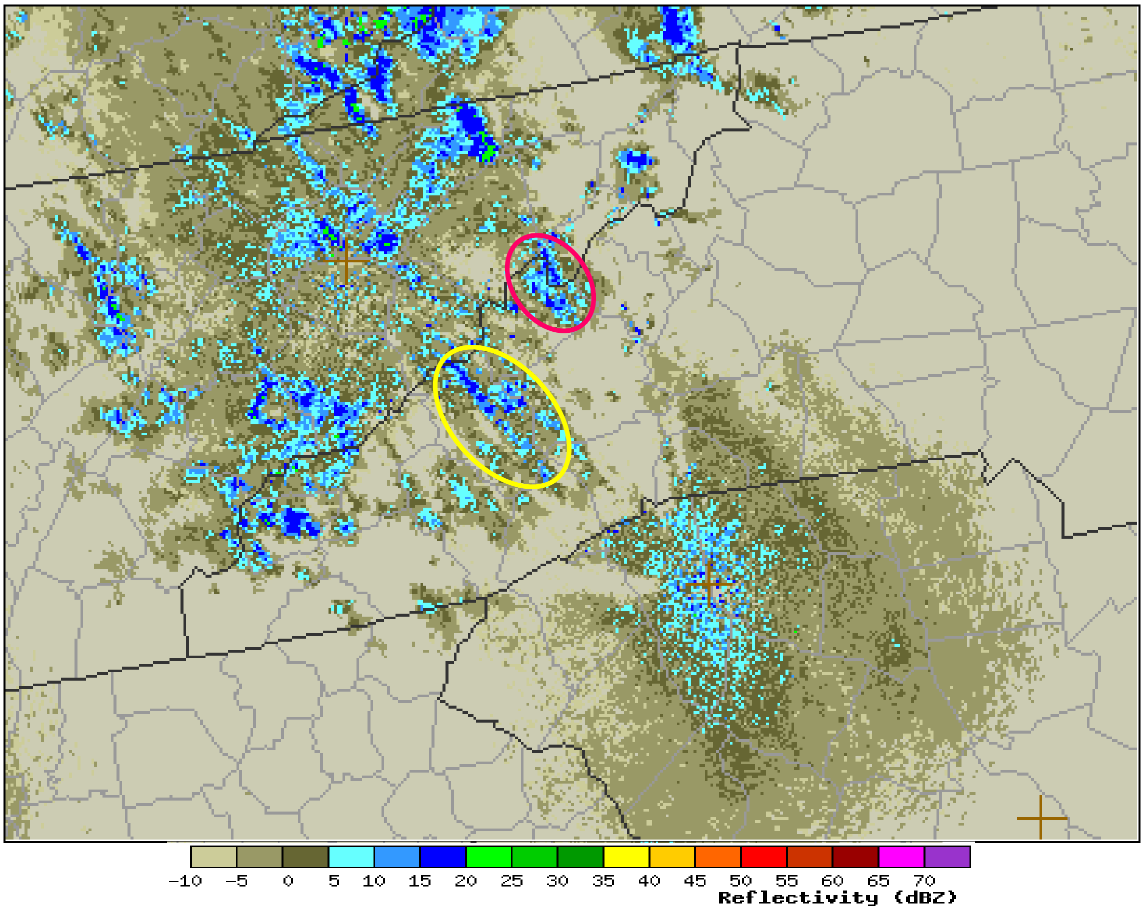

Fig. 11. Composite radar reflectivity increasing across the Balsam Mountains (yellow oval) and Madison County (red oval) at 0557 UTC.

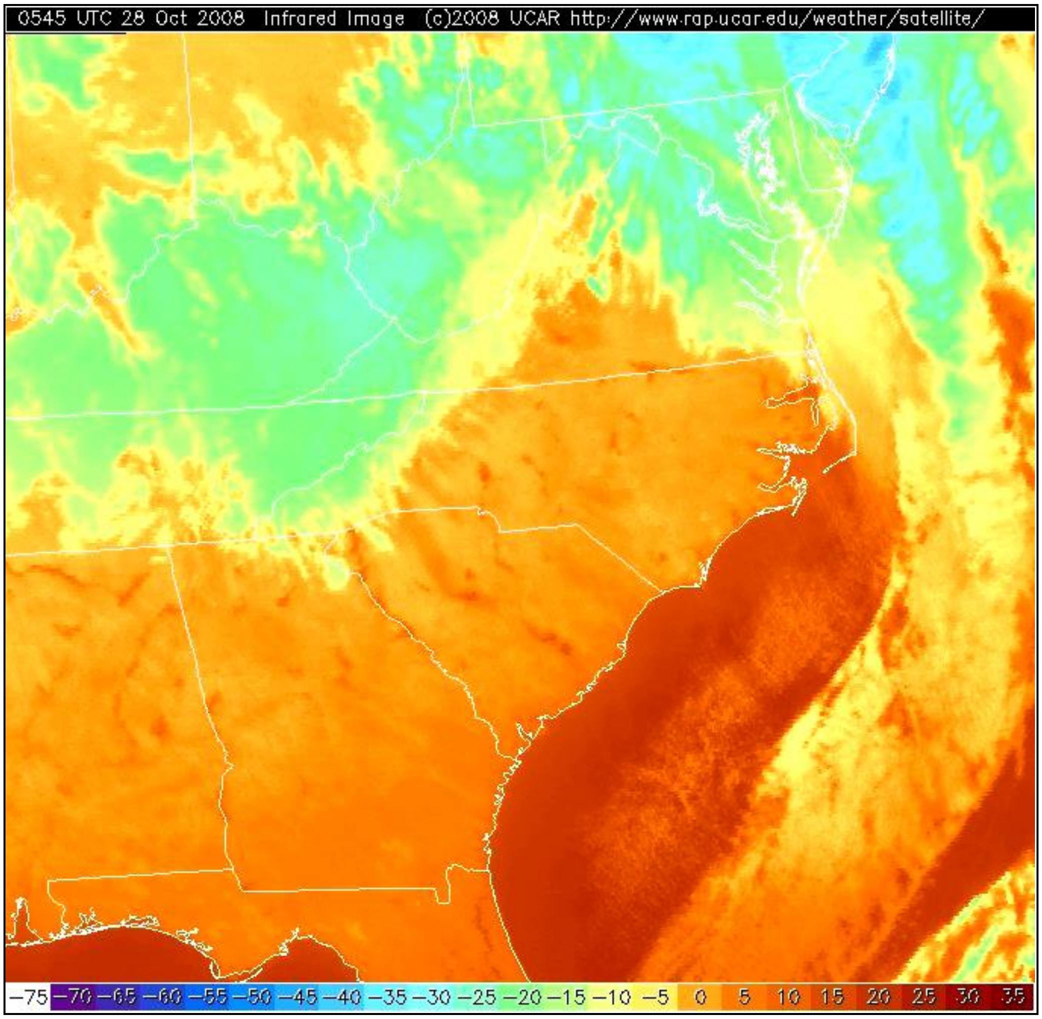

Fig. 12. GOES infrared image at 0545 UTC indicating available low level moisture upstream of the North Carolina mountains.

Low level moisture across east Tennessee began to wane by 1145 UTC when satellite images showed decreasing clouds upstream of the North Carolina mountains (Fig. 13). The 1200 UTC 28 October Bufkit WRF NAM sounding for TRI (not shown) indicated northwest winds continued within the moist layer, however, the average winds between the surface and 900 mb (approximately 2000 ft) had weakened 12 kts and backed 33 degrees since 0000 UTC (Fig. 14). This decreased the component of the wind perpendicular to the mountains in the lower levels, and therefore would reduce the magnitude of mechanical lift and cooling needed to support continued saturation. Snow showers continued in western North Carolina at 1157 UTC as evident on the composite radar reflectivity image. By 1456 UTC, snow showers diminished across the area (Fig. 15) and were observed mainly across the northern part of the forecast area on composite radar reflectivity.

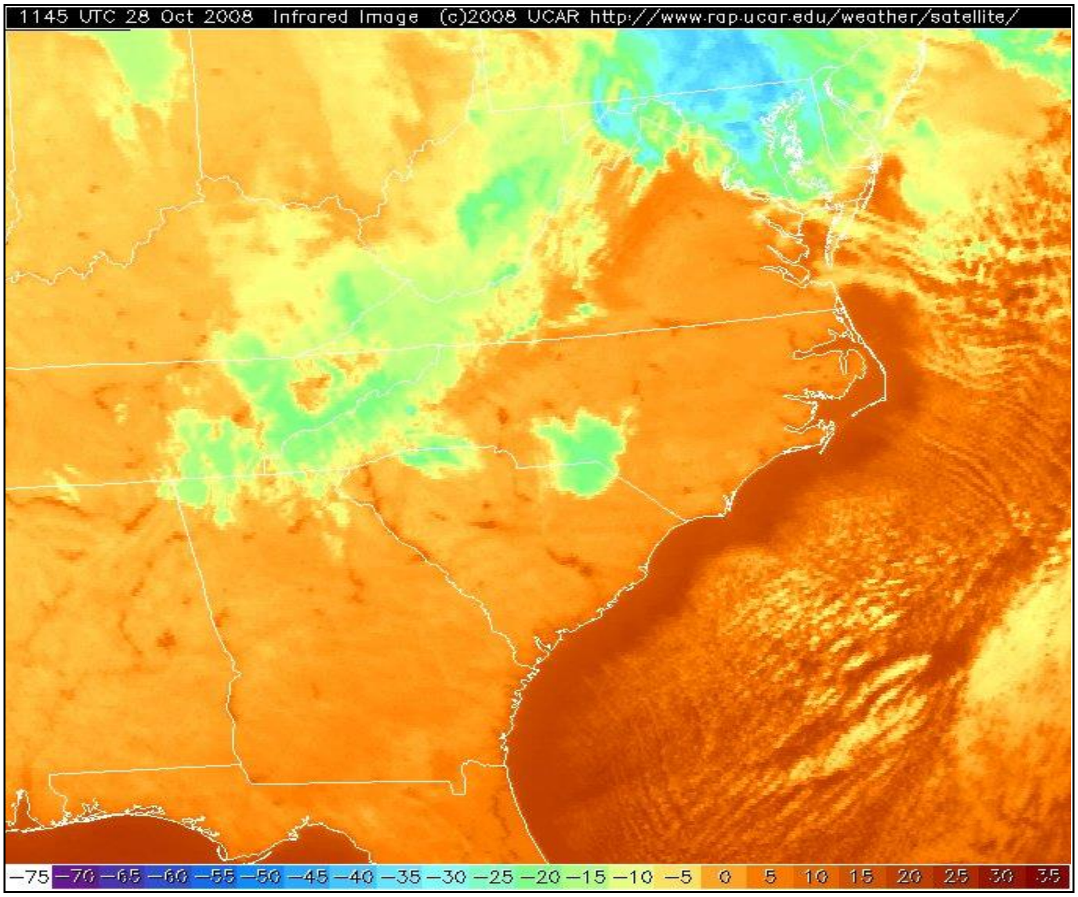

Fig. 13. Infrared image at 1145 UTC showing decrease in cloud cover across east Tennessee.

WRF NAM TRI 0000 UTC					WRF NAM TRI 1200 UTC		
p	ddd	ff			p	ddd	ff
907	319	23			904	299	10
913	319	23			910	296	9
918	319	23			915	292	9
923	319	23			921	289	9
928	319	22			926	292	9
933	319	22			931	288	9
938	319	22			941	291	10
943	318	21			945	290	10
947	318	20			950	282	10
952	318	19			954	281	8
956	317	17			959	273	7
961	317	14			963	252	4
avg	**318**	**21**			**avg**	**285**	**9**
			Δddd	**Δff**			
			33	**12**			

Fig. 14. Difference in average winds (blue numbers) below 900 mb at TRI between 0000 UTC and 1200 UTC 28 Oct (p = pressure in millibars, ddd = direction in degrees, ff = speed in knots).

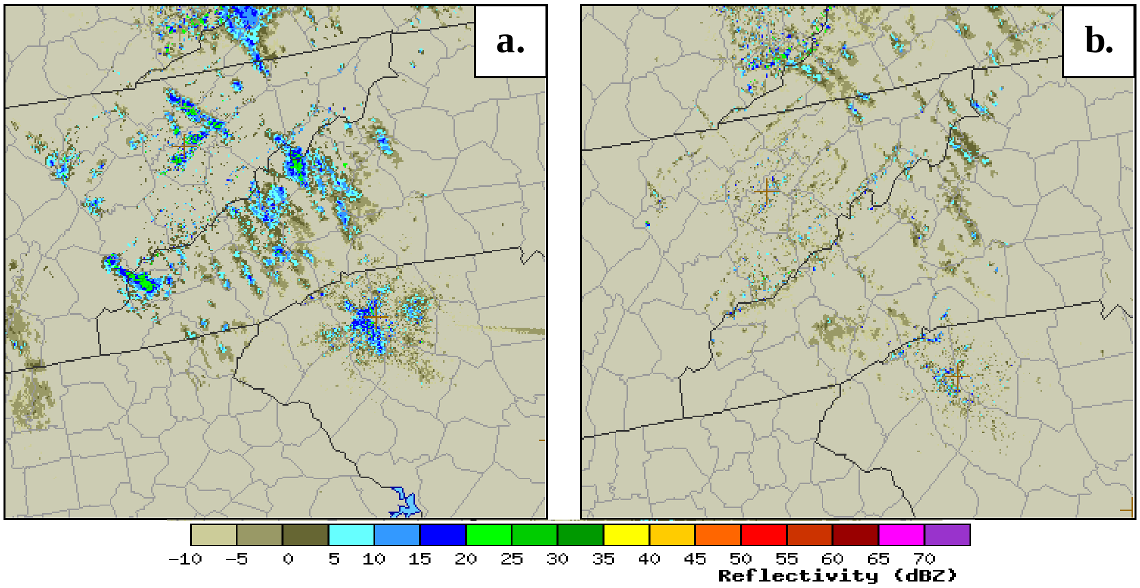

Fig. 15 Snow showers continuing across the North Carolina mountains including the southern mountains at 1157 UTC (a) and diminished composite reflectivity at 1456 UTC (b).

The Asheville Regional Airport (AVL) ASOS reported light snow through 1434 UTC. Between 1354 UTC and 1413 UTC the visibility was 0.75 mile in snow. Information obtained from North Carolina county officials indicated generally a trace to one inch of snow had fallen across the mountain valleys west of Asheville. Spotters in the same area reported 1 to 3 inches of snowfall at locations above 2500 ft MSL.

The National Weather Service Cooperative Observer Network (COOP), the Community Collaborative Rain, Hail and Snow Network (CoCoRaHS), and staff from the National Climatic Data Center (NCDC) provided additional snowfall reports in the relatively data sparse region. One member of the NCDC staff who lives near Weaverville, NC reported 2 inches of snowfall. This amount correlated well with a five-hour period of composite reflectivity returns seen across this area.

The greatest snowfall amount received from the COOP and CoCoRaHs observing networks was at Cruso in Haywood County, where 3 inches was reported. Two inches fell at Newland, Weaverville, Canton, Mars Hill, and Mount Mitchell. Other locations from Flat Springs to Bakersville and Black Mountain measured 1 to 2 inches. A trace to less than 1 inch of snow fell across the southern North Carolina Mountains. A public report of 6 to 8 inches was received from the Cowee Mountains of western Jackson County. A photograph accompanying the report can be seen in Fig. 16.

Fig. 16. Snowfall accumulation on tractors located in the Cowee Mountains (Photo courtesy of Mark Haskett).

4. Summary

A northwest flow snow event occurred in western North Carolina on 28 October 2008. The snow followed the passage of a cold front which was followed by a period of northwest, upslope flow across the southern Appalachians. Moisture for the snowfall was provided by an extensive cumulus and stratocumulus cloud field that developed west of the mountains.

The event was relatively early in the season, yet it was not unprecedented. The 0.5 inch snowfall at Grandfather Mountain, NC was the tenth greatest October snow accumulation since 1955. The earliest date on which measurable snow fell at Grandfather Mountain was 14 October 1977. This was the first time at least a trace of snow had been observed in the Asheville area on this date since 1910.

The climatologically favored northwest flow upslope regions identified by Perry et al. (2007) received most of the snowfall. In general, the largest accumulations were measured at elevations above 3000 ft MSL. Surface temperatures across the mountain valleys remained around freezing which limited the snow accumulation in those areas. The scattered nature of the precipitation elements, which is typical of northwest flow snow events, prevented widespread, uniform snow accumulations from occurring. However, locally heavy snow was observed in the Cowee Mountains where precipitation rates were possibly enhanced by upslope flow in horizontal convective rolls.

REFERENCES

Perry, L.B., C.E. Konrad, and T.W. Schmidlin, 2007: Antecedent upstream air trajectories associated with northwest flow snowfall in the southern Appalachians. *Wea. Forecasting*, **22**, 334–352.

Schultz, D. M., D. S. Arndt, D.J. Stensrud, and J.W. Hanna, 2004: Snowbands during the cold-air outbreak of 23 January 2003. *Mon. Wea. Rev.*, **132**, 827–842.

Cotton W. R., and R.A. Anthes, 1989: *Storm and Cloud Dynamics*. Academic Press, 883 pp.

Acknowledgements

Many thanks to Larry Lee, the Science Operations Officer (SOO) at the Greenville Spartanburg Forecast Office. Larry Lee provided scientific reasoning and many improvements leading to several revisions of the final report. The radar and satellite data was retrieved from the National Center of Atmospheric Research. Upper air maps were obtained from the NOAA/NWS/NCEP Storm Prediction Center and the surface maps were obtained from the NOAA/NWSNCEP Hydrometeorological Prediction Center.